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Heat Transfer Measurements

on

REFRIGERATED-FOOD TRAILERS

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U.S. DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Marketing Research Division

in cooperation with

U. S. DEPARTMENT OF COMMERCE
National Bureau of Standards
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PREFACE

This study is part of a broad program of research to improve the design and performance of transportation equipment used in the movement of agricultural products, as a means of improving and expanding the marketing of farm products.

To date there has been no standard method to measure the performance, or efficiency, of a refrigerated-food trailer body. This study is a basic step in the development of a practical method to rate these trailers in order that they may provide the protection that will prevent the deterioration and spoilage of perishable foods in transit to market.

Agriculture-Washington June 1958

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HEAT TRANSFER MEASUREMENTS ON REFRIGERATED-FOOD TRAILERS

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HIGHLIGHTS

The Agricultural Marketing Service and the National Bureau of Standards cooperated in studies to determine the time required to attain substantially steady-state (steady flow) heat transfer in a typical refrigerated-food semitrailer under two laboratory procedures and to develop and describe an accurate method for measuring brine temperatures during rating tests of trailers. Tests of a commercial 35-foot semitrailer with 6 inches of glass fiber insulation in walls, ceiling, and floor showed that steady-state heat transfer was approached after the trailer had been subjected to the desired temperatures for a minimum of 28 hours. About 20 percent more time was required to reach steady-state heat transfer when a fixed quantity of heat was supplied to the interior of the trailer than when the desired difference between the interior and exterior temperatures was established as soon as possible after starting the test.

Recommended methods of measuring temperature are described in the report as well as the procedures used in the metering heat sink method for rating refrigerated trailers.

As a result of this and earlier research by these two agencies, a joint industry-Government project has been initiated to develop a standard method for measuring the cooling requirements of motortruck trailers while maintaining the temperatures required to protect frozen foods in transit.

INTRODUCTION

The increasing use of frozen food products in recent years has brought about the development of new types of railroad, motortruck, and truck-trailer equipment to carry a variety of such products for long distances at the low temperatures required to maintain their quality. The Agricultural Marketing Service has been interested in and worked on some of the technical problems of frozen food transportation for several years. The National Bureau of Standards has made a number of measurements of the heat transfer of refrigerated semitrailers.

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The National Bureau of Standards and the Agricultural Marketing Service conducted a comparative field study of 7 typical refrigerated semitrailers in Edgewater Park, Miss., in May 1956. The trailers were submitted by members of the Truck-Trailer Manufacturers Association at the request of the American Trucking Associations, Inc. The results of this test showed wide variations in the heat transfer characteristics of the 7 vehicles and in the performance of their refrigerating units, and thus emphasized the need for standard rating techniques. Concurrently with this activity, the National Bureau of Standards was developing, in cooperation with the Quartermaster Research and Engineering Command, Department of the Army, a prototype apparatus referred to as a metering heat sink apparatus, for measuring the heat transfer of a refrigerated structure (such as a trailer) while the structure was refrigerated under conditions normal to intended service.

In December 1956, the Agricultural Marketing Service requested the National Bureau of Standards to study various methods of measuring heat transfer of refrigerated-food vehicles. The study was preliminary to the selection and instrumentation of an accurate and practicable method, which could be adopted as a standard for the measurement of trailer performance by the trucking and truck manufacturing industries. The request included the following three tasks:

1. Make laboratory tests of a typical 35-foot refrigerated-food semitrailer to determine the length of time required for steady-state heat transfer under 2 different methods of controlling internal heat.

2. Develop and describe a practical and accurate method of measuring temperature differences in secondary refrigerant lines of the proposed metering heat sink apparatus.

3. Prepare charts and models which may be used to demonstrate and explain the metering heat sink method to industry and other interested groups.

This paper describes heat transfer studies made on a typical insulated trailer using the reverse heat loss method and two different laboratory procedures of controlling the heat input to the vehicle. 2/ Since previous

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2/ In the reverse heat loss method, the trailer interior is heated to a temperature higher than that of the surrounding outside or ambient air. With this method, the flow of heat through the walls is reversed from the usual direction of flow in a refrigerated trailer.

cooperative work by the Department of Agriculture and the National Bureau of Standards suggested that heat transfer measurements on insulated trailers should preferably be made with the normal direction of temperature gradient, the basic principles of the proposed metering heat sink method are described. Temperature-measuring techniques for such heat transfer studies are also illustrated and described.

HEAT TRANSFER TESTS

The first step undertaken was to make heat transfer studies of a typical refrigerated-food semitrailer to determine the period of time required to approach steady-state heat transfer under two different sets of controlled conditions.

A secondary purpose of this test was to evaluate the adequacy of heat transfer tests of short duration--some reported to be as short as 10 to 12 hours--that have been used to determine the heat transfer rate of trailers designed for refrigeration service.

Test Equipment and Procedure

A new 35-foot refrigerated-food semitrailer was used for the 3 tests made. Figure 1 is a photograph of the interior of the semitrailer looking through the doors. The fan and heater shown in the figure were not used for these tests.

The trailer was equipped with a mechanical refrigeration unit, which remained in place during the tests but was not operated. The trailer had an aluminum exterior skin, a plywood interior skin, and 6 inches of glass fiber insulation in the walls, floor, and ceiling; it also had 6 meat rails on the ceiling. It was equipped with a tandem wheel assembly (2 axles, 4 double wheels) and weighed approximately 13,000 pounds.

For the tests, the trailer was placed in an enclosure in which the temperature could be controlled. An electric heater and two 16-inch desk fans were placed in the trailer and means were provided to record the amount of power supplied to them. Thermocouples were installed on the interior and exterior of the trailer to measure the temperatures of the air inside and outside the vehicle. Four thermocouples were mounted outside the trailer, 6 inches from the exterior surface; and one set of 12 thermocouples was mounted inside the trailer, 6 inches from the interior surfaces. Another set of 3 thermocouples was installed inside the trailer, 1 in the center of the vehicle and the other 2 at midheight on the longitudinal centerline, one-sixth of the interior length from either end. These 2 sets were installed for comparative purposes, to determine whether the set of 3 would be adequate for a proposed standard test procedure. The trailer was empty during all of the tests.

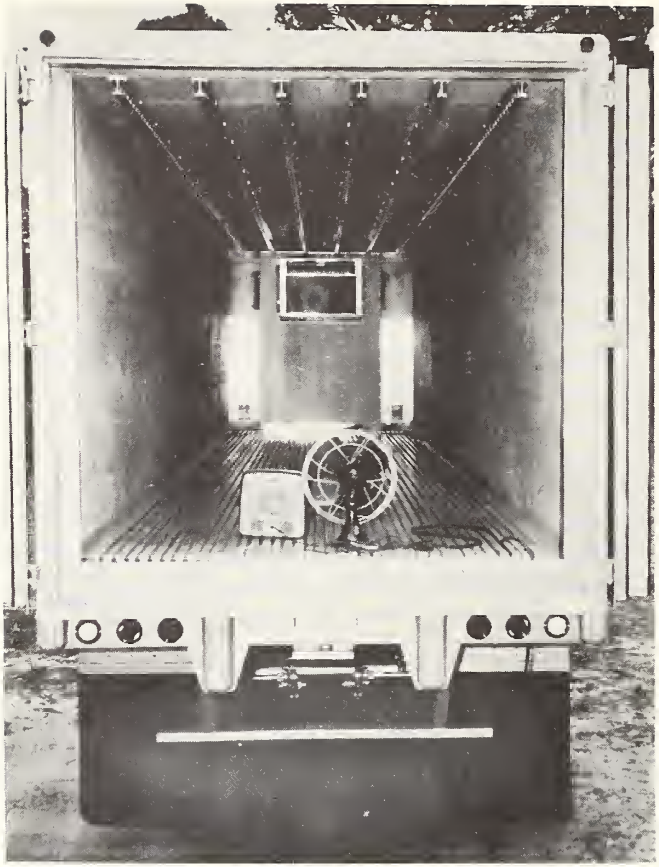

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Figure 1.--Rear view of semitrailer used in tests with rear doors open.

For the first test, the trailer was left open and allowed to come to the same temperature as the ambient temperature of 70° F. The doors were closed, the interior fans started, and sufficient electrical heating supplied to bring the interior temperature of the trailer to about 150° in approximately 2½ hours. A thermostat in the trailer regulated the heating to hold the interior temperature at 150°. The power required was observed at regular intervals for more than 45 hours.

At the beginning of the second test, the interior surface of the trailer body was less than 2½° F. above the 70° temperature of the surrounding air. The doors were closed, the interior fans started, and the amount of heating required in the first test to hold the interior at a steady-state temperature of 150° was supplied. The interior temperature of the trailer, therefore, rose much more slowly than in the first test. This test also was continued for more than 45 hours.

The third test consisted of reducing the ambient temperature from 70° F. to 60° at the conclusion of the second test, with all other conditions unchanged, to determine the length of time required for the heat transfer rate to again become constant.

Results of Heat Transfer Test

The rates at which the apparent heat transfer or heat loss and interior temperature approached constant values in tests 1, 2, and 3 are shown in figure 2. For the purpose of this report, the "apparent heat transfer rate" is defined as the interior heat input rate divided by the product of the surface area of the trailer and the inside-outside temperature difference.

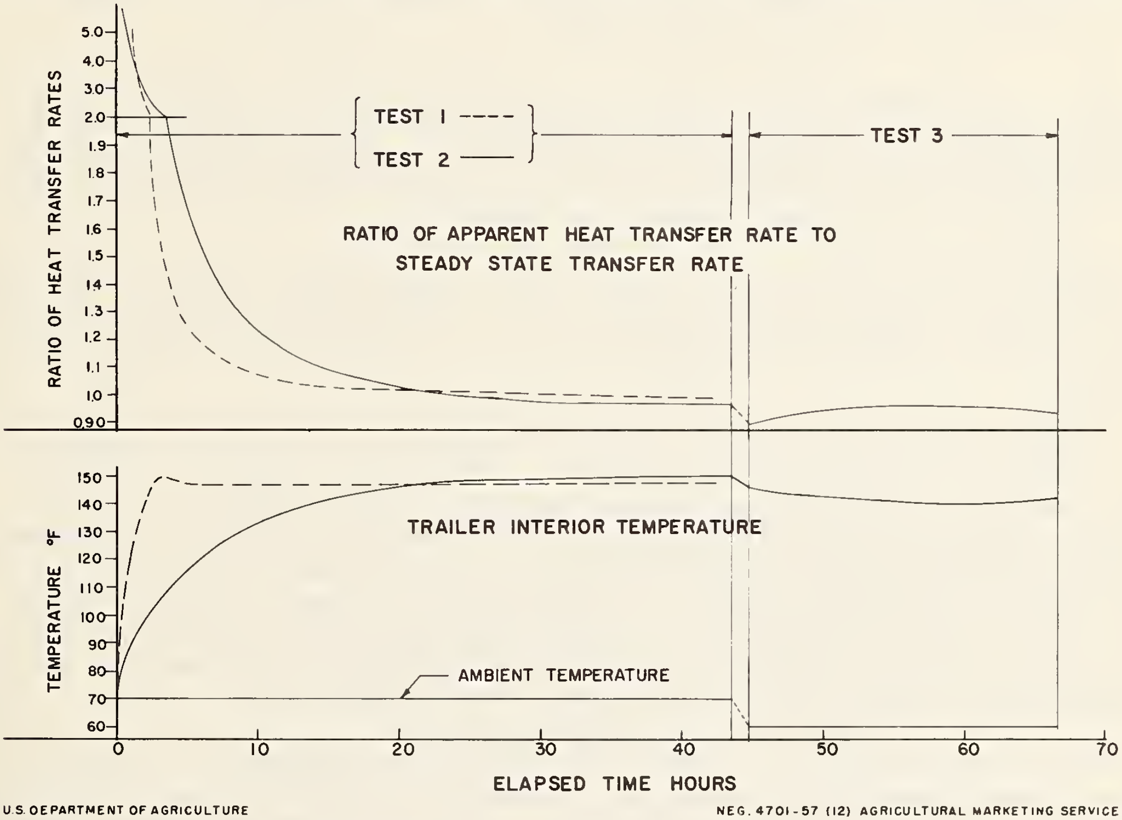

Figure 2.--Time required to reach steady-state heat transfer in tests 1, 2, and 3.

Theoretically, steady-state would never be obtained under the methods of heat application used for these tests. However, a practical approach would be to decide that sufficient precision would be attained in determining the heat loss when the average apparent heat transfer rates for each of 2 consecutive 6-hour periods did not differ by more than 1 percent. By observing and recording temperatures and heat inputs during the test, one could determine when the rate of change of apparent heat transfer had reached the desired value. For example, in test 1 the data show that the apparent heat transfer rate had reached the desired value after 28 hours, whereas in test 2 the same degree of stability was reached in 34 hours. Thus, a reasonably precise value of the steady-state heat transfer of a refrigerated-food trailer of the type, weight, and degree of insulation typified by the test semitrailer could not be corroborated by this method in less than about 34 hours with the thermostatted heat input method of test 1 or about 40 hours by the fixed heat input method used in test 2, because of the additional 6 hours required to establish the steadiness of the heat transfer rate.

In test 3, which was in reality a continuation of test 2, more than 10 hours elapsed after changing the ambient temperature from 70° F. to 60° before steady-state was again approached.

The average of the temperatures indicated by the set of 3 thermocouples along the centerline of the trailer differed less than one degree from the average of the set of 12 thermocouples located 6 inches from the interior skin, indicating that the interior air circulation rate was adequate to provide essentially a uniform interior temperature.

The heat loss rates at the end of tests 1 and 2 were slightly less than 100 British thermal units per hour per degree Fahrenheit temperature difference (100 B.t.u./hr. x °F) and the values for the 2 tests differed by less than 2 percent.

A higher initial heat input rate was required for the method used in test 1 than for the method used in test 2. This has no important economic significance when the interior of the trailer is heated for test purposes. However, if the trailer were refrigerated to produce a temperature gradient through the walls of the trailer in the normal direction, it would require appreciably more refrigeration to use the method of test 1 than that of test 2. The results in figure 2 indicate that only about 20 percent more testing time would be required when using a fixed cooling or heating rate as exemplified by test 2 than for the method used in test 1.

During the 3 tests, the trailer decreased approximately 40 pounds in weight. Water began to drip from approximately 26 points around the bottom edge of the exterior skin soon after the interior temperature reached 150° F., and continued for about 4 hours in test 1. Again, in test 3, when the ambient temperature was lowered from 70° to 60°, water dripped for about 3 hours from most of the same places. No volumetric measurement was made of the amount of water which dripped from the trailer, but it is believed that the weight reduction can be attributed to the water driven from the vehicle during the tests. The movement of water vapor in the insulation undoubtedly affected the rate of temperature change during the first few hours of test 1 and 3, but probably had no important effect as steady-state was approached.

MEASURING TEMPERATURE DIFFERENCES IN SECONDARY REFRIGERANT LINES

Concurrent studies of methods for determining the heat transfer rate of refrigerated structures, made by the National Bureau of Standards for the Quartermaster Research and Engineering Command, Department of the Army, have indicated that a metering heat sink method has several advantages over the reverse heat loss method. The metering heat sink method provides for refrigerating the interior of the structure under test to the temperature at which it is designed to operate, thus producing a mean temperature of the insulation comparable to that in actual service. Because the temperature gradient is also in the normal direction and because the ambient temperature and humidity are maintained at selected design values, this method provides for a movement of air and water vapor into or through the walls of the structure that is typical of actual usage.

Figure 3 shows the design of the thermocouple wells and piping adjacent to them which has been found satisfactory for the accurate determination of the temperature difference of the secondary refrigerant or brine entering and leaving the trailer under test, and entering and leaving the calorimeter incorporated in the metering heat sink apparatus. Five copper-constantan thermocouples are series-connected with the "cold" junctions in 1 of the 2 wells and the "hot" junctions in the other. Since the voltage produced per degree Fahrenheit temperature difference by a single pair of copper-constantan junctions is about 20 microvolts, the 5 thermocouples in series produce a measuring signal of about 100 microvolts per degree of temperature difference of the 2 wells. Figure 4 shows the wiring circuit for such a differential thermocouple.

Figure 5 is a view of a calibrated heater, such as was used in the prototype metering heat sink apparatus, showing the piping arrangement and thermocouple wells. Figure 6 shows the construction of a typical thermocouple well using a conventional 3/4-inch pipe tee. Conventional commercial electronic indicating or recording potentiometers have been found satisfactory. With a brine temperature difference of 8° F., the 5 thermocouples in series produce a signal of about 800 microvolts and since these potentiometers can indicate or record with an accuracy of from 3 to 10 microvolts, depending on type and range, the temperature difference can readily be measured within 2 percent. Correction must be made for the change in voltage produced by the differential thermocouples per degree of temperature difference with change in the absolute temperature of the thermocouple. A single thermocouple is shown in each well in figure 4 for the purpose of measuring these absolute temperatures.

DEVELOPMENT AND USE OF WORKING MODELS OF TEST APPARATUS

A working model of a metering heat sink apparatus capable of measuring the heat leakage of a model trailer was constructed to illustrate the functioning of the metering heat sink method. Figure 7 shows schematically

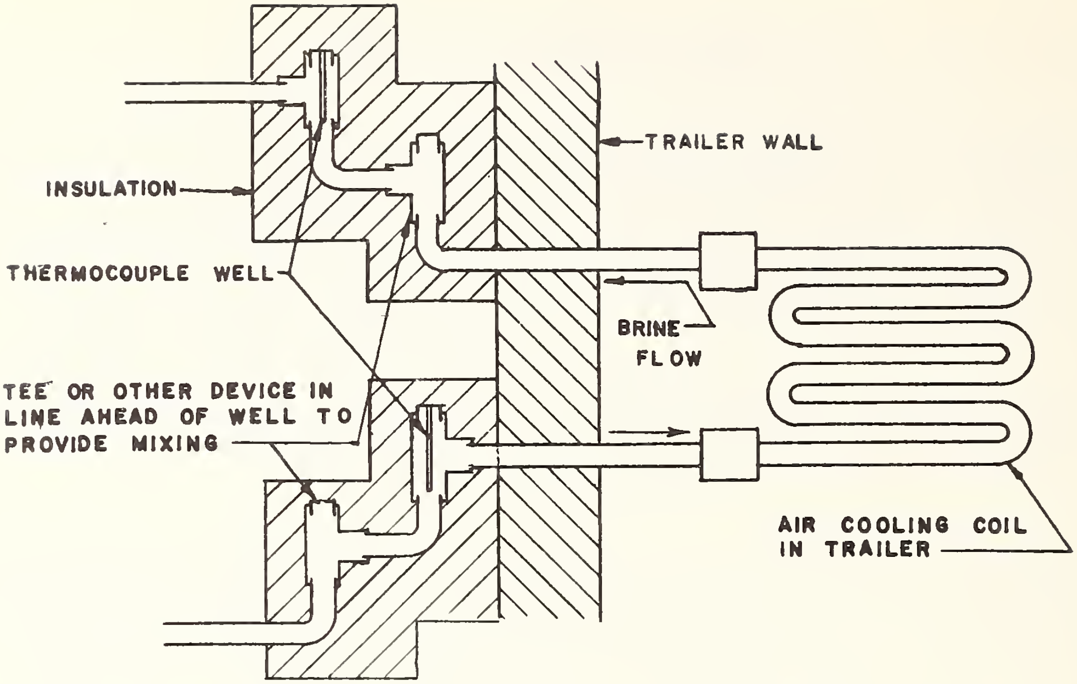
INSULATION
THERMOCOUPLE WELL
TRAILER WALL
BRINE FLOW
TEE OR OTHER DEVICE IN LINE AHEAD OF WELL TO PROVIDE MIXING
AIR COOLING COIL IN TRAILER

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Figure 3.--Location of thermocouple wells in secondary refrigerant circuit.

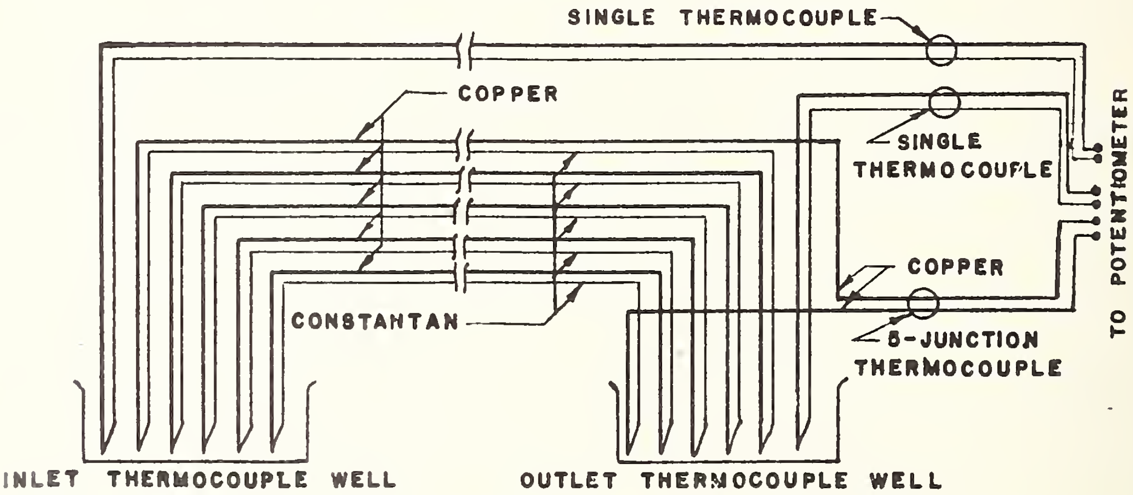

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Figure 4.--Thermocouple circuit for measurement of temperature difference.

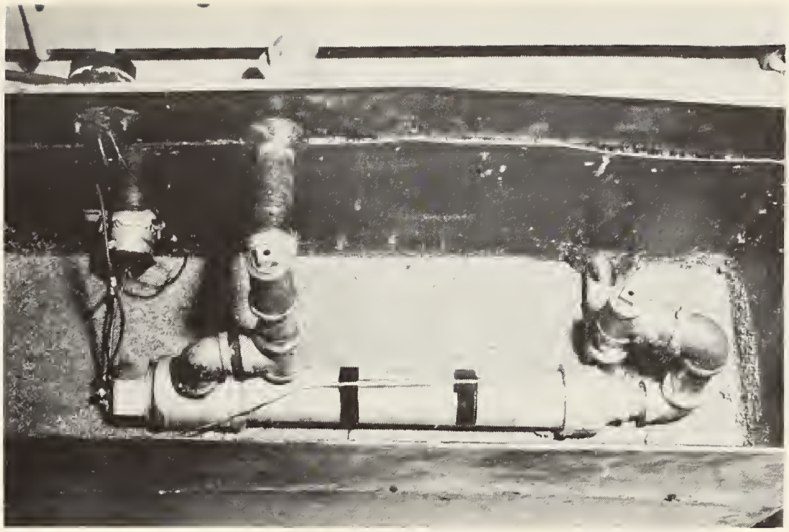

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Figure 5.--View of a calibrated heater, showing the piping arrangement and thermocouple wells.

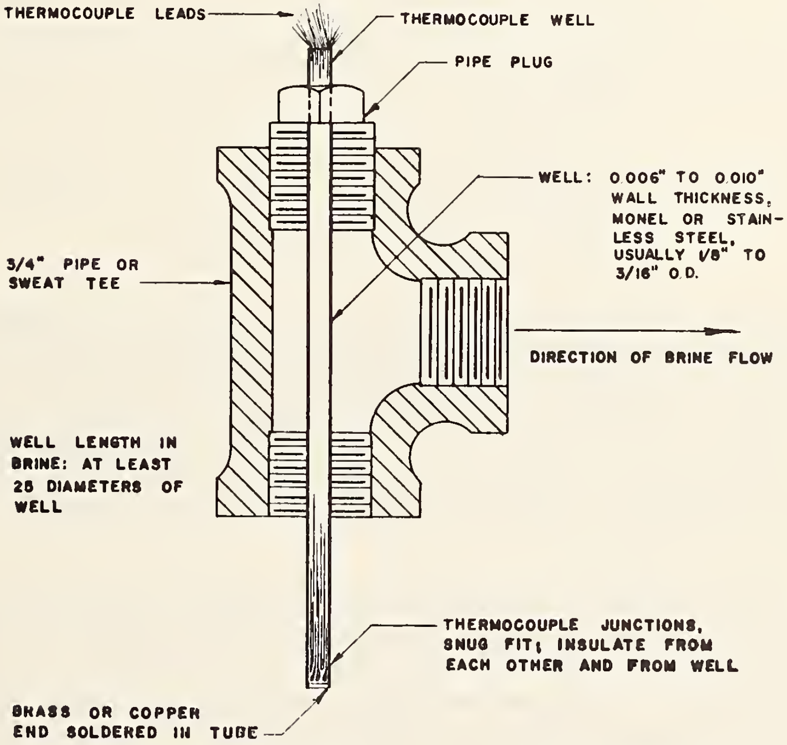
THERMOCOUPLE LEADS
THERMOCOUPLE WELL
PIPE PLUG
WELL: 0.006" TO 0.010" WALL THICKNESS, MONEL OR STAINLESS STEEL, USUALLY 1/8" TO 3/16" O.D.
3/4" PIPE OR SWEAT TEE
DIRECTION OF BRINE FLOW
WELL LENGTH IN BRINE: AT LEAST 25 DIAMETERS OF WELL
THERMOCOUPLE JUNCTIONS, SNUG FIT; INSULATE FROM EACH OTHER AND FROM WELL
BRASS OR COPPER END SOLDERED IN TUBE

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Figure 6.--Typical thermocouple well in 3/4-inch fitting.

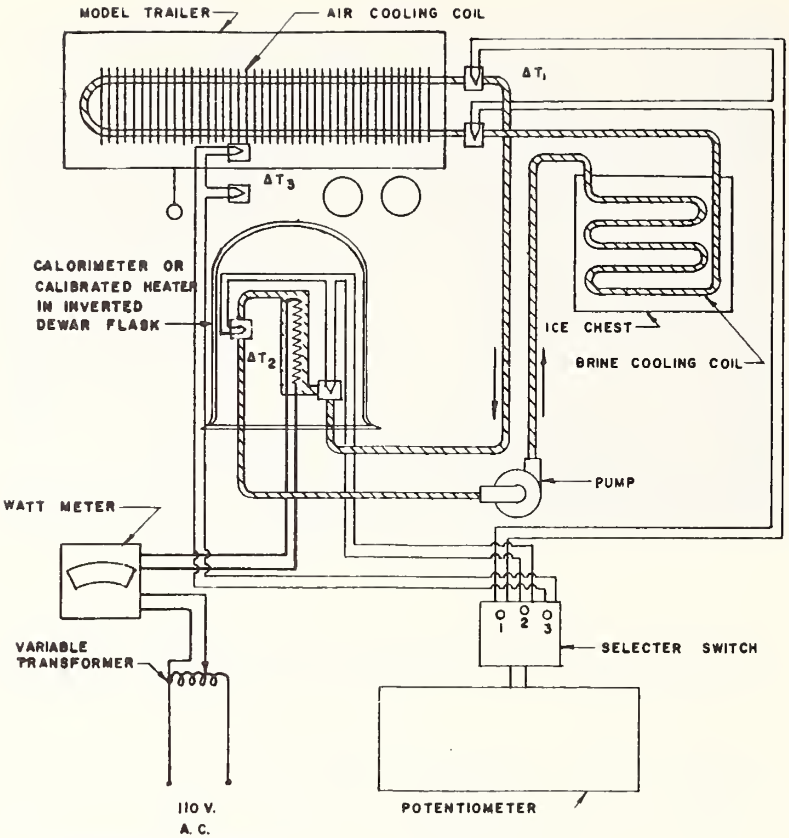

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Figure 7.--Schematic circuit for model of metering heat sink.

the circuit of this demonstration apparatus, which used ice for cooling and water as the secondary refrigerant or "brine." Figure 8 is a photograph of the working model. The trailer is at the upper left and the ice chest at the extreme right in the picture. The potentiometer, wattmeter, voltmeter, and variac are grouped in the lower part of the photograph at the front of the table, and the calibrated heater can be seen under the inverted Dewar flask on the stool. The pump that circulated the chilled water through the circuit is located behind the stool.

Another working model of the metering heat sink, using a mechanical refrigerating unit and a heated enclosure over the model trailer, is shown in figure 9. This model was constructed prior to the program outlined in this report, but was modified for demonstration at several advisory group meetings in the Department of Agriculture. Enlarged graphs showing the results of heat loss tests 1, 2, and 3 were prepared and used in conjunction with the working model of the metering heat sink for illustrating the rate of change in heat transfer of a typical commercial vehicle.

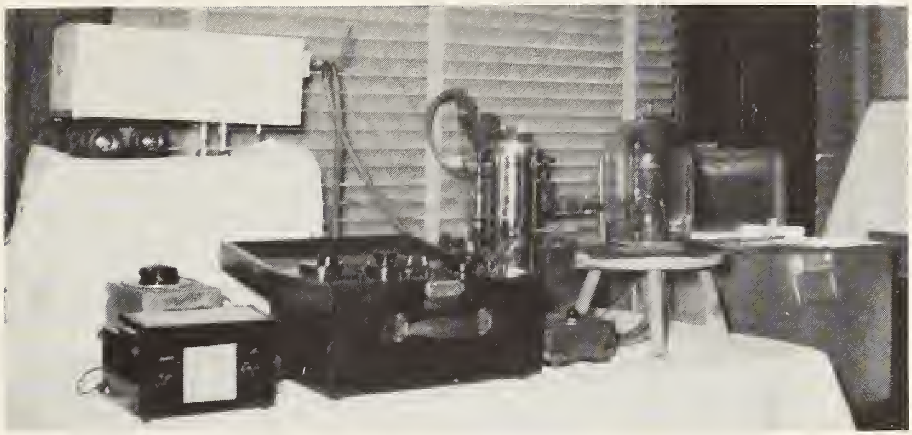

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Figure 8.--Working model of metering heat sink.

The test models were utilized to demonstrate the principles of the metering heat sink method to representatives of the trucking and truck-trailer manufacturing industries, the Refrigerated and Frozen Products Research Advisory Committee, and the Transportation Research Advisory Committee of the Department of Agriculture. These two committees are composed of nongovernmental representatives of the agricultural industry; they were selected for their qualifications and experience to advise the Department in its research programs relating to the refrigeration and transportation of food products.

FORMULATION OF INDUSTRY-GOVERNMENT PROGRAM FOR FURTHER RESEARCH

Upon consideration of the metering heat sink method of measuring trailer performance, these groups recommended that the work be continued and expanded; whereupon a joint industry-Government program was prepared for developing instrumentation and testing techniques that would make the method suitable as a standard rating procedure.

Formal cooperative agreements between the Agricultural Marketing Service, the National Bureau of Standards, and the Truck-Trailer Manufacturers Association, for the execution of the program, were signed in July 1957. The Truck-Trailer Manufacturers Association, the major industry sponsor, acted as the contracting party for the motor carrier industry and its suppliers.

Funds and equipment were contributed to the project by manufacturers of truck-trailers, motortruck tractors, mechanical refrigerating equipment, and insulating materials, and by the Truck Body and Equipment Association and the American Trucking Associations, Inc. The Truck-Trailer Manufacturers Association acted as the coordinator.

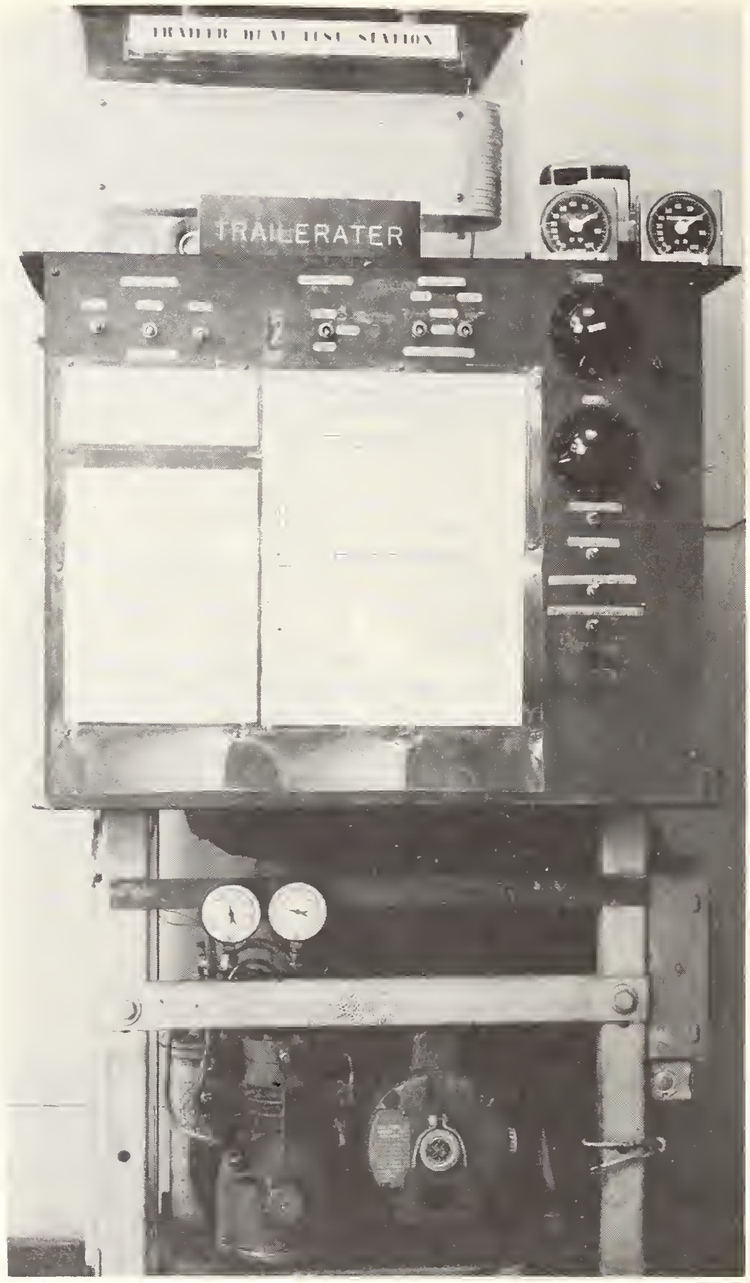

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Figure 9.--Working model of metering heat sink using a mechanical refrigerating unit.

The work is being done at the National Bureau of Standards with the assistance of engineers and technicians of the Agricultural Marketing Service. A structure was built and was provided with equipment for the control of temperatures, humidity, and air flow. By the end of September 1957, both laboratory and road tests of 2 truck-trailers had been completed. It is expected that the program on rating techniques for trucks and trailers will be continued through the summer of 1958.